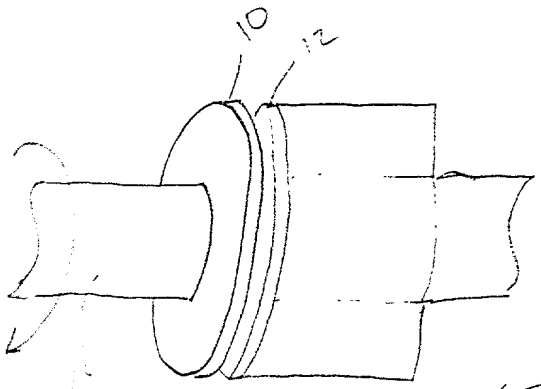


FIG. 1

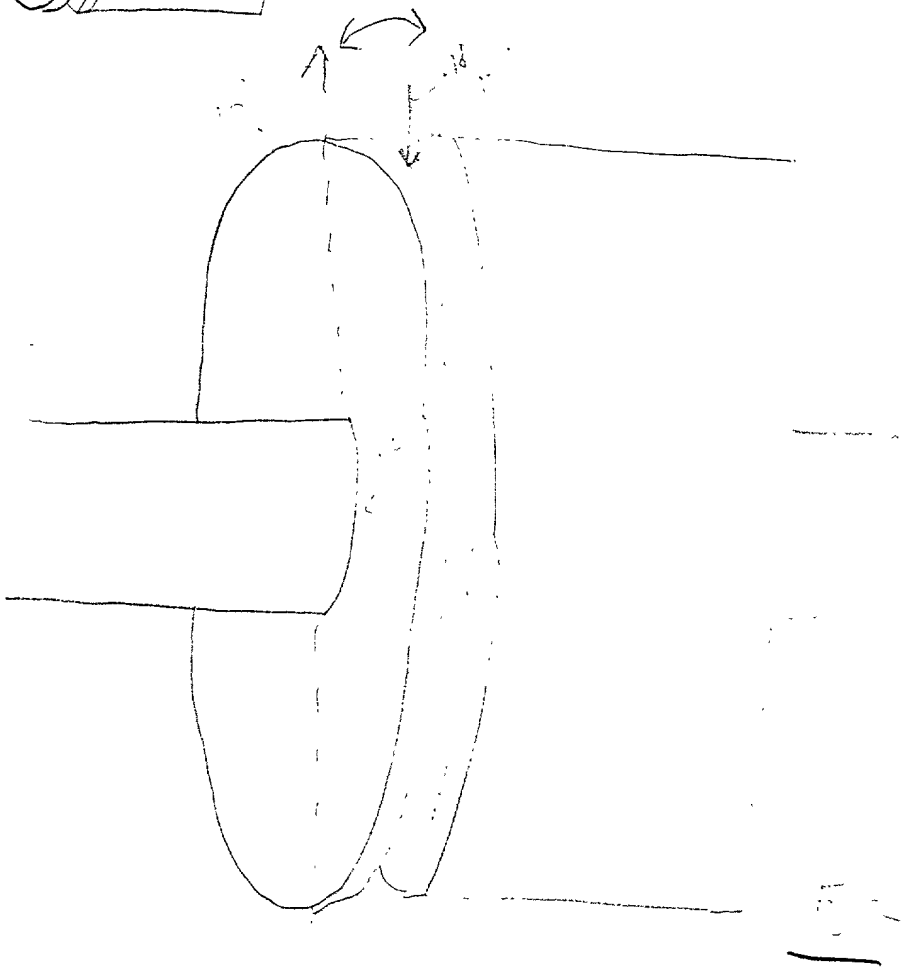
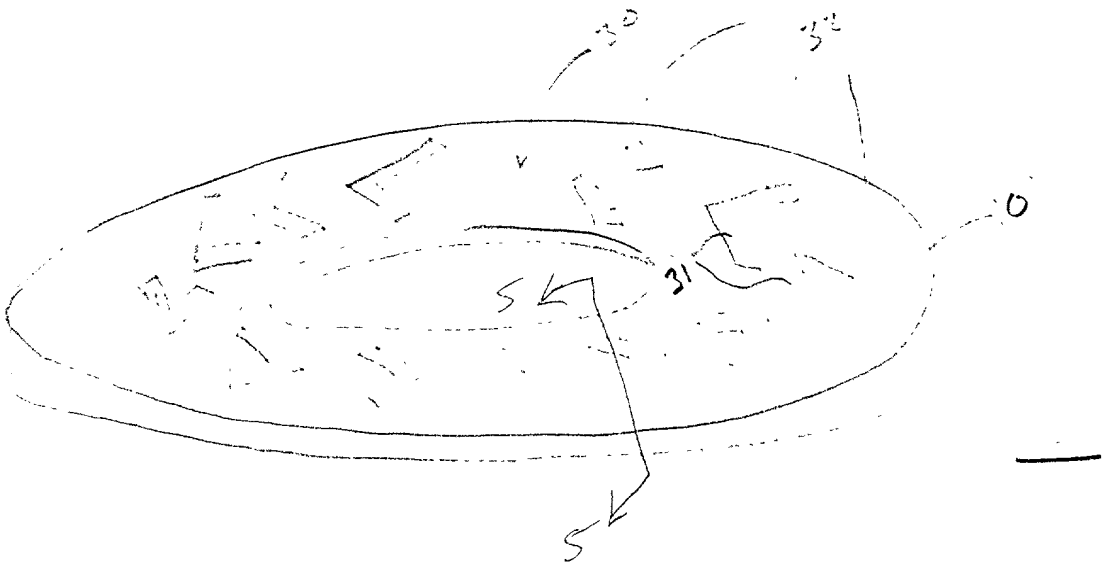
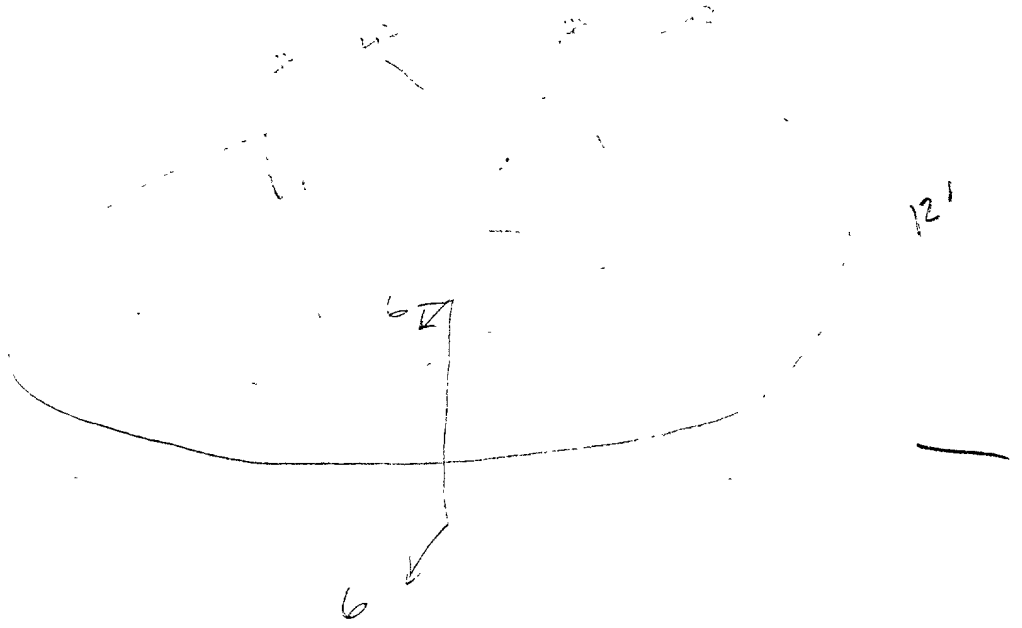


FIG. 2





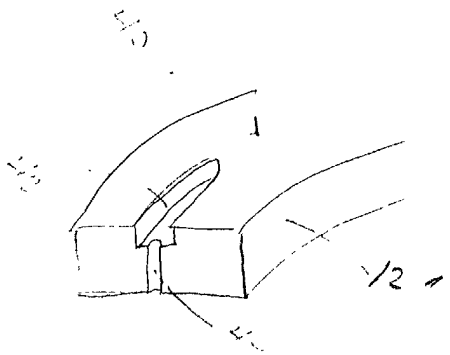


Fig 6

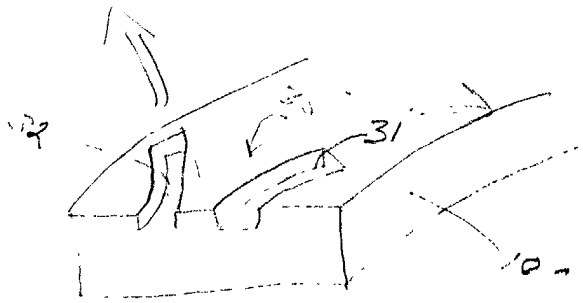


Fig 7

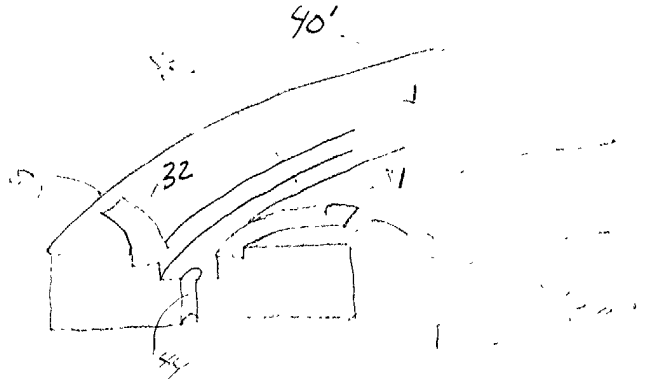


Fig 8

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explained later. Normally, the deep feeding groove is not segmented as shown in Figure 2 for manufacturing reasons.

Preferably, seal face patterns shown in Figure 1 or 2 are on the face of stator ring **200**. But they can be a combination of the imprints on rotor and stator faces **200,201**. For example, the feeding groove **104** and hole **105** can be on the stator ring **100** while the groove **101,106** and dam sections **102,107** are on rotor ring **201**. In such case, the two hydrodynamic sections (groove section) **101,106** can extend and meet at the center. Please note that the number of pairs of groove and land can be different for inner and outer seal sections **109,110** in the non-segmented design. However for ease of plotting, same numbers of groove-land pairs are used in all the figures in this disclosure. In addition, the pumping grooves **101,106** are normally 200-900 micro inches in depth; they are shown exaggerated in some plots to better demonstrate the seal configurations.

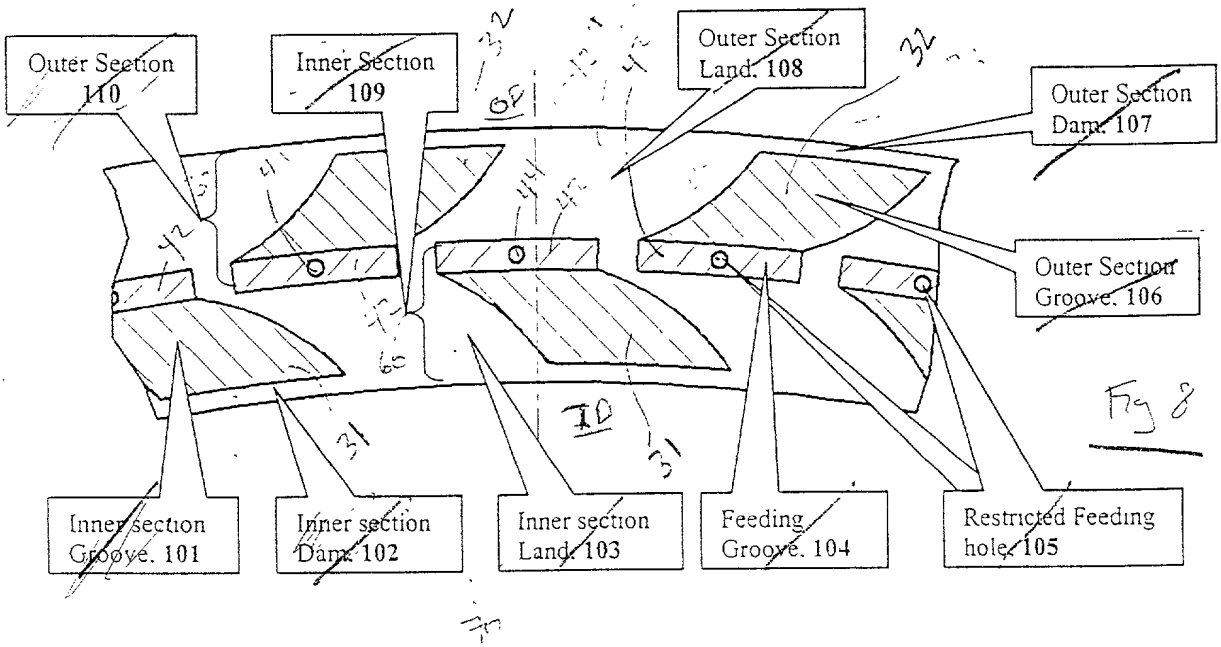

Figure 1. Typical seal face layout for segmented feeding grooves

As mentioned before, a very interesting implementation of the above described idea is to put divert grooves **101,106** on the rotor sealing face **203** but have feeding holes and deep feeding groove on the stator sealing face **202**. This is quite natural if the rotor is made of hard material. The deep feeding groove can be round **131** or rectangular **132** at the bottom. Alternatively, we can put feeding hole **105** and deep feeding groove **104** on rotor face **201**, but leave pumping grooves **101,106** on stator as shown below. The

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feeding holes **105** are aligned in an angle with the rotating axis against the rotational direction. In this way, the rotation effect makes the feeding more effective. The configuration is shown in Figure 3. But for high-speed rotor, the feeding hole **105** may create serious stress concentration. Therefore the first arrangement is preferred.

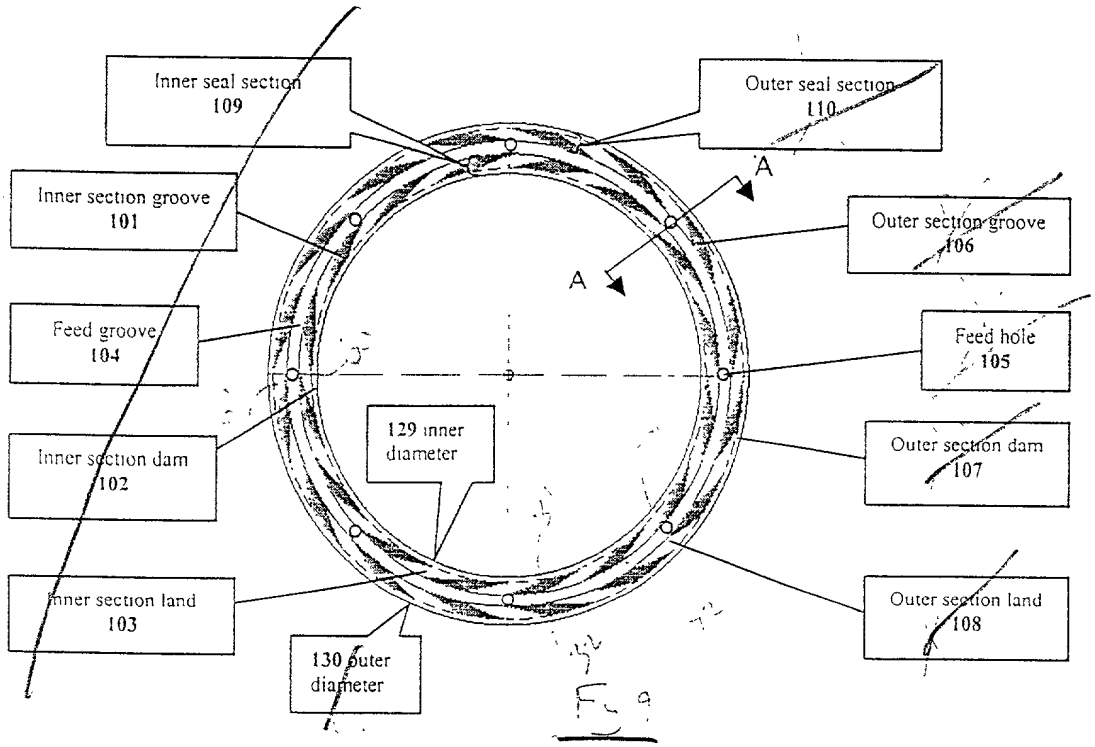

Fig 9

Figure 2. Non-Segmented Divert Groove Face Seal

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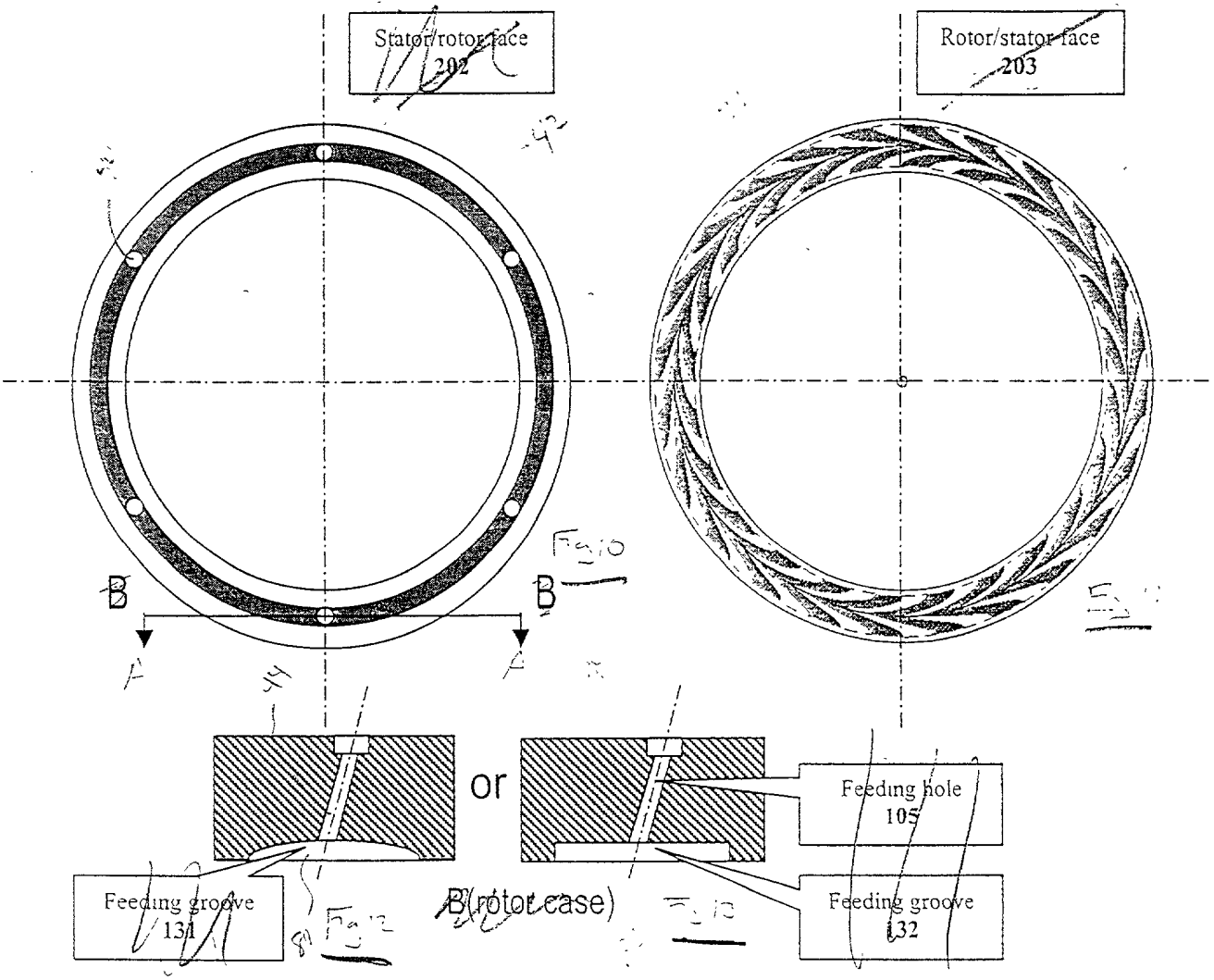

Figure 3. Divert double-groove seal

For the convenience of demonstration, in all the figures shown hereafter, we assume all the features are put on the stator ring **100**.

Figure 4 shows a cut side view of the stator. The stator ring **100** is mounted to a stator holder **121** and supported by a bump **123** on the back. The bump is also called back seat **123**. Its main function is to provide additional closing force and serves as a support point for the stator ring **100** to rock on. Retracting spring **122** holds the stator back if the pressure difference across the seal is small. This feature is used to

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Key elements of the invention:

A unique feature of the new face seal is that it pumps fluid from inside to edges. This allows the seal to work at tough conditions of severe face deflection. Since the fluid enters from the center, face coning will never cut off fluid from getting into the seal face. The groove profiles are designed to have desirable pumping effects and film stiffness. Even though we still call it double-spiral groove seal, the groove shape does not necessarily have to be a spiral. As a matter of fact, the spiral curves are usually approximated by circular arcs for the ease of manufacture. Furthermore, this invention suggests use of groove profile curving forward **119** instead of conventional curving backward in cases that stronger pumping effects are needed. The alternative groove profiles are shown below.

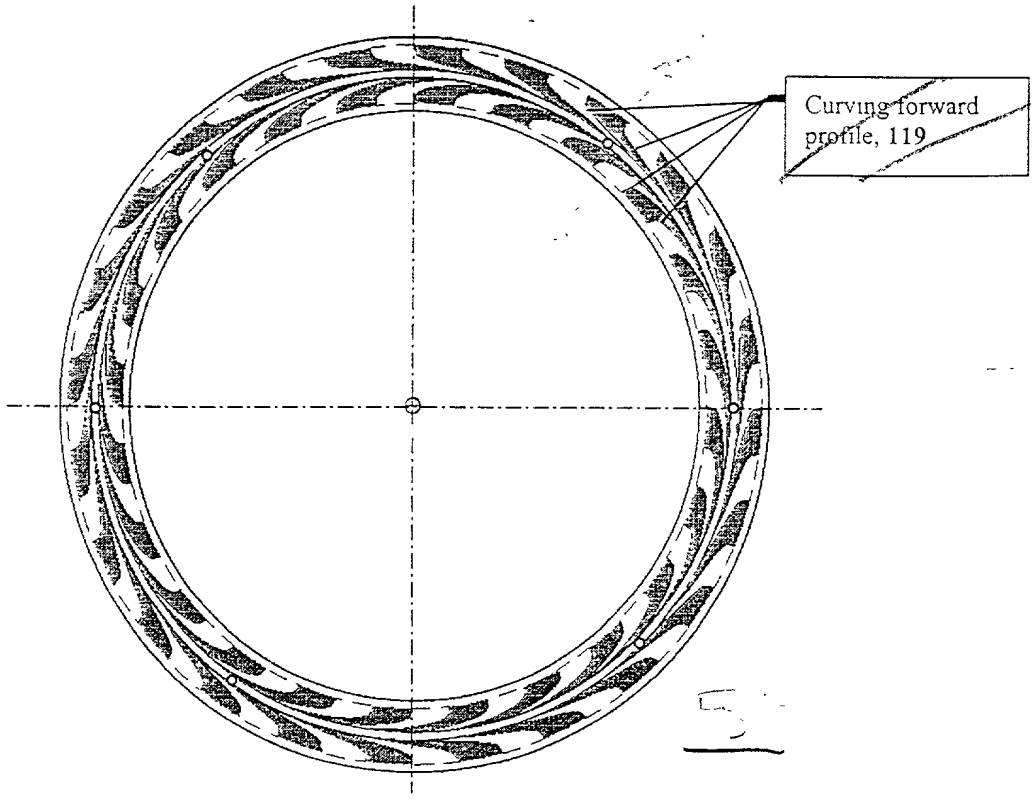

Figure 5. An alternative groove profile

In order to make the stator ring **100** adaptive to rotor face **201**, the stator ring is designed to be flexible in terms of coning deflection. Therefore the thickness of the stator ring is chosen to be as small as the manufacturing process can allow maintaining flatness of the seal face. The flexibility of the stator ring combined with the restoration capability of the seal face makes the seal highly adaptive to the rotor ring face **201**. The mechanism is explained in the following.

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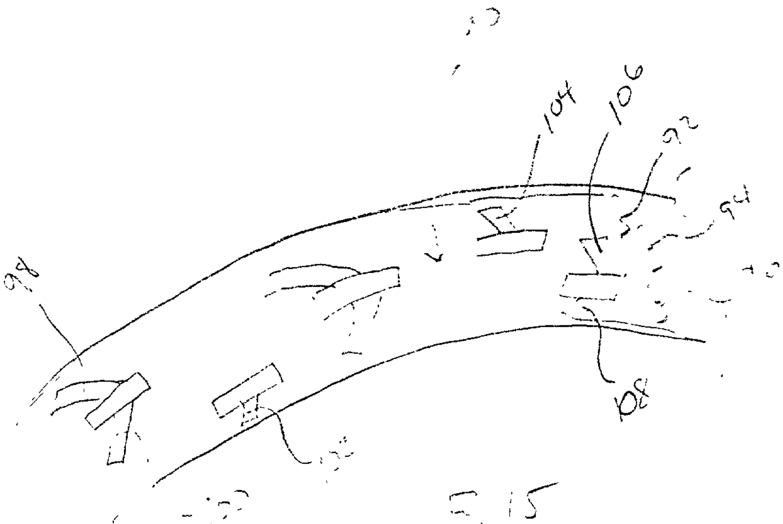

Fig 15

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Before we go on to discuss the stator responses to rotor deflection, let us define the sign of coning deflection first. Following the face seal convention, if the coning causes a divergent gap **128** from outer diameter **129** to inner diameter **130**, we define the coning as negative. If the coning by either stator or rotor causes a convergent seal gap **128** between the stator and rotor sealing faces **200,201**, the coning is defined as positive.

Figure 6 shows a typical pressure distribution **150** on the seal face at a design operation condition. The rotor sealing face **201** and the stator sealing face **200** are in a parallel orientation. The total forces **151** from the outer seal section, feeding groove and inner section and their equivalent acting positions are illustrated with vectors. The stator ring experiences a net moment of zero.

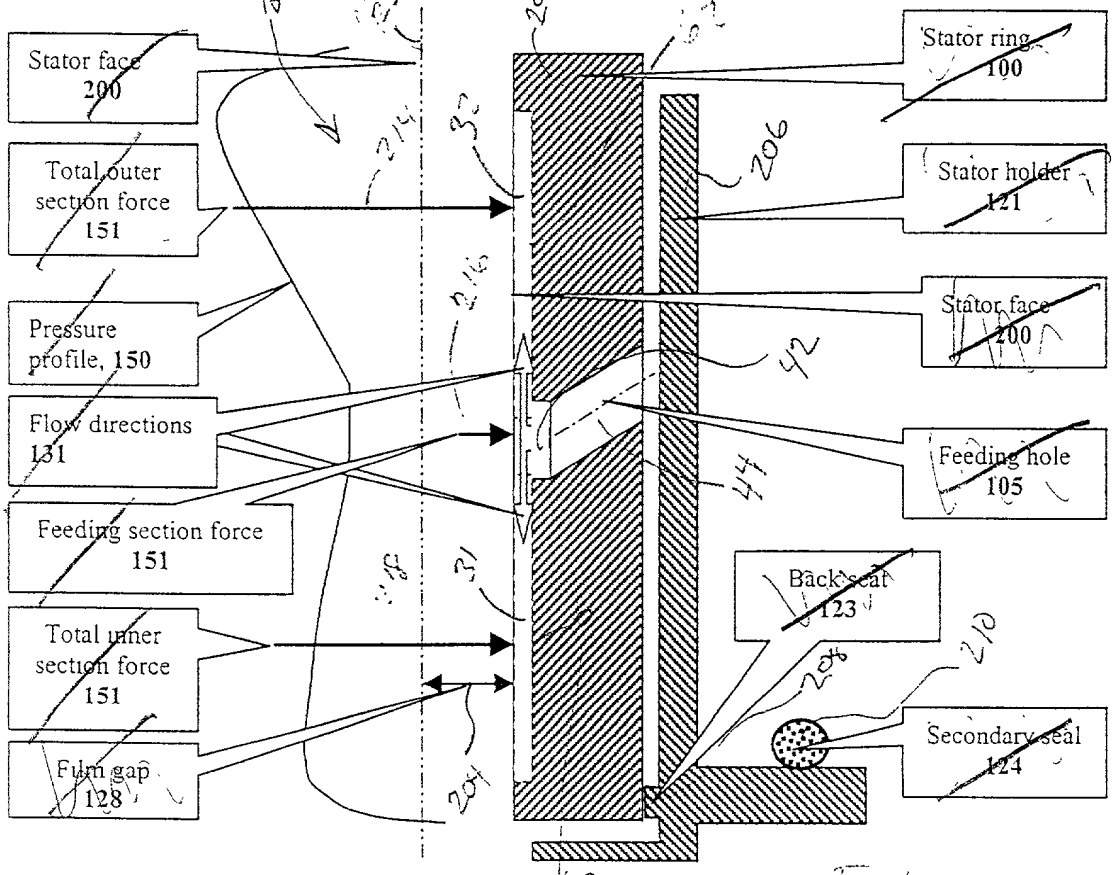

Figure 6. Design condition without rotor deflection

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When the rotor face **201** deflections cause negative coning, the outer seal section **110** is working in a convergent film (refer to the flow direction **131**). That makes the groove **106** work more effectively to create higher pressure in the hydrodynamic section. Therefore, the outer seal section **130** generates more positive moment to open up the clearance at outer diameter **130**. Meanwhile, the inner seal section **109** is working at a divergent film. That reduces the hydrodynamic effects of the grooves **101**. Less pressure, and therefore less negative moment, is generated by the inner seal section **109**. The net increase of positive moment causes the stator ring **100** to cone positively and form a uniform film thickness as shown in Figure 7.

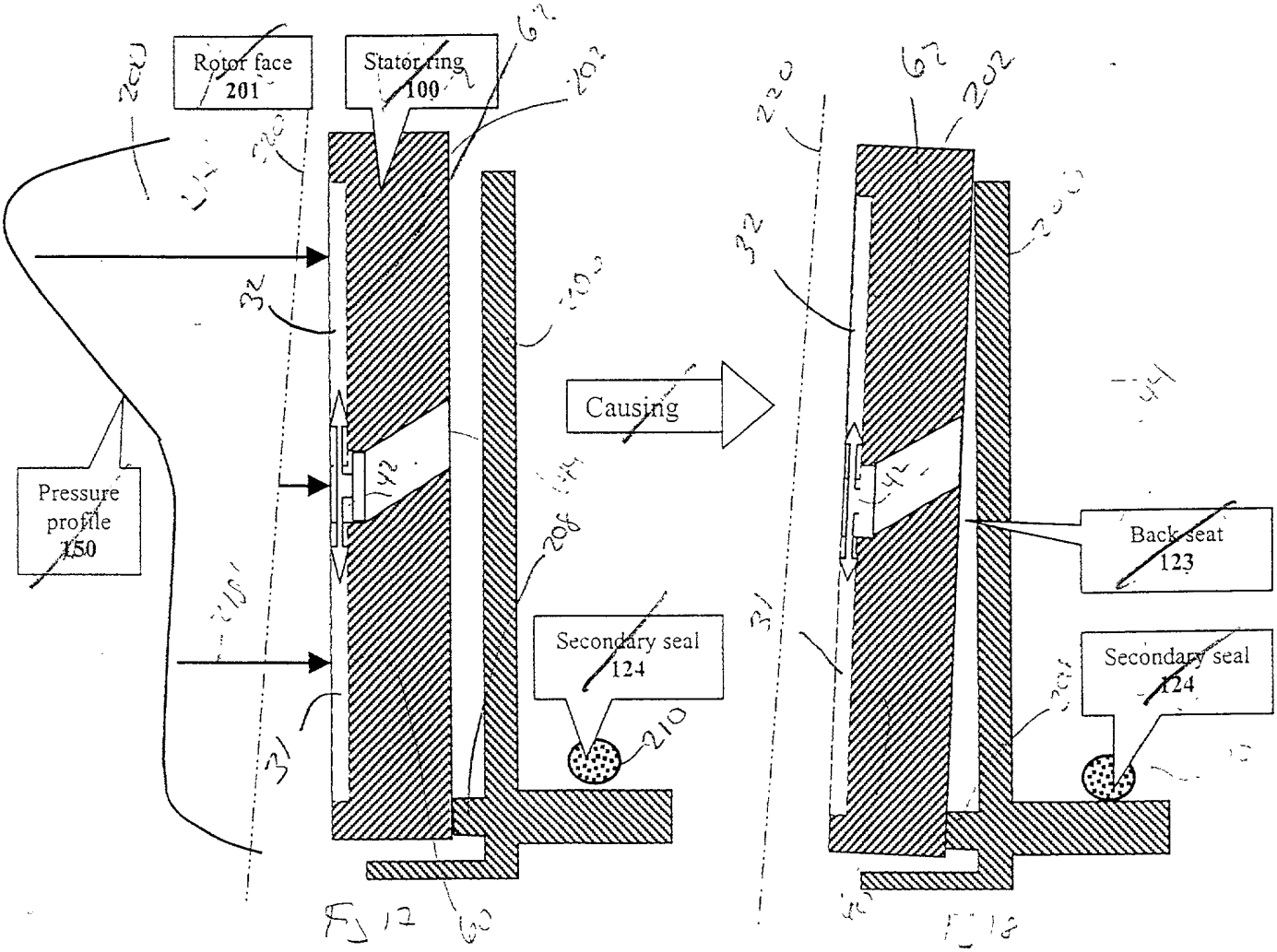

Figure 7. Negative coning of rotor prompts stator ring to cone positively

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When the rotor face **201** deflections cause positive coning effect, the outer seal section **110** is working in a divergent film. That makes the groove **106** work less effectively to create high-pressure zone in the hydrodynamic section. Therefore, the outer seal section **110** generates less positive moment. Meanwhile, the inner seal section **109** is working at a convergent film. That increases the hydrodynamic effects of the grooves **101**. Larger pressure, and therefore larger negative moment, is generated by the inner seal section **109** to open up the clearance at inner diameter **129**. The net increase of negative moment causes the stator ring **100** to cone negatively and form a uniform film thickness as shown in Figure 8.

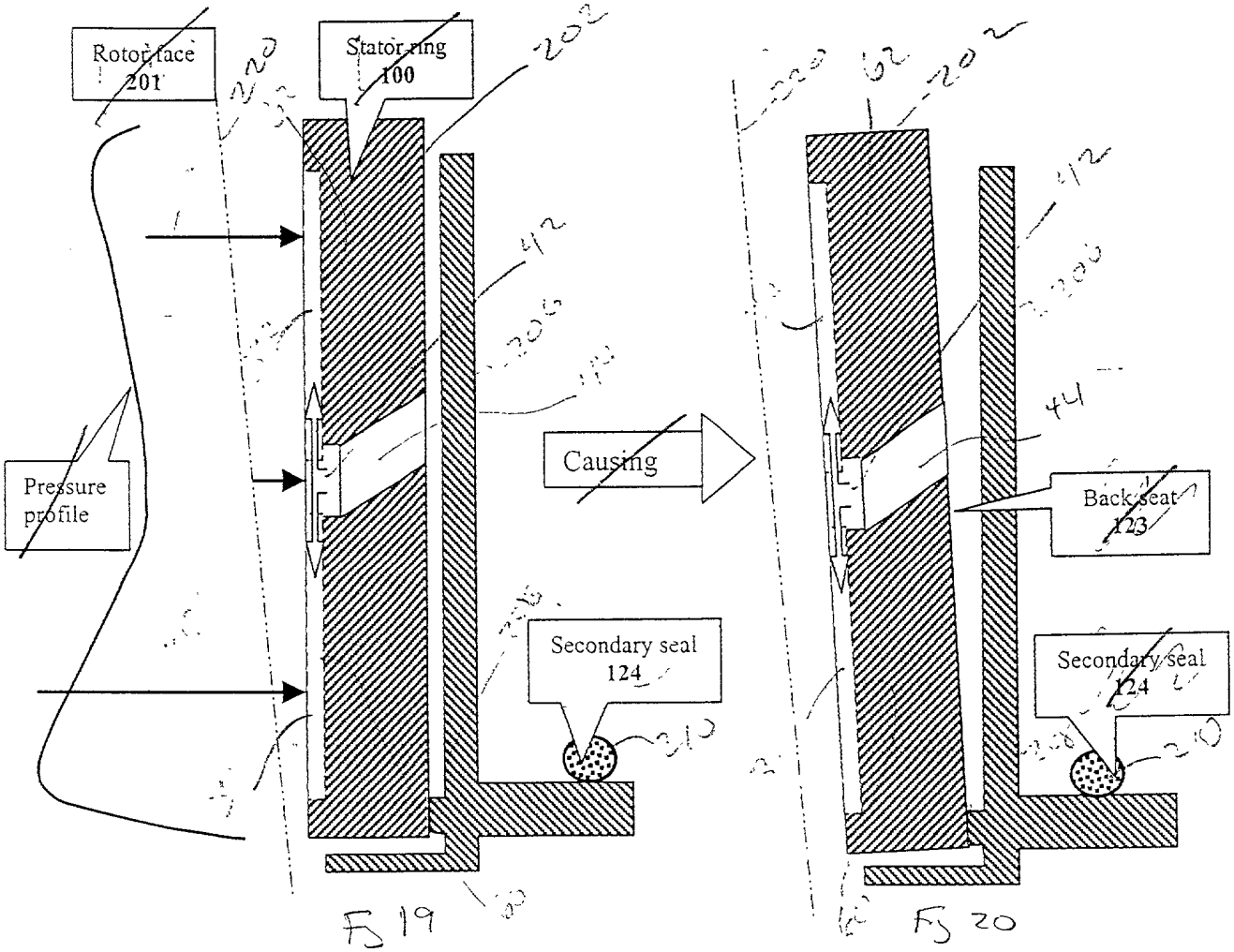

Figure 8. Positive coning of rotor prompts stator ring to cone negatively

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prevent seal faces from touching and rubbing during engine start-up and shut-down. A typical stator is shown below. Please note that the top does not necessarily correspond to outer diameter 130, it rather corresponds to wherever the system pressure is.

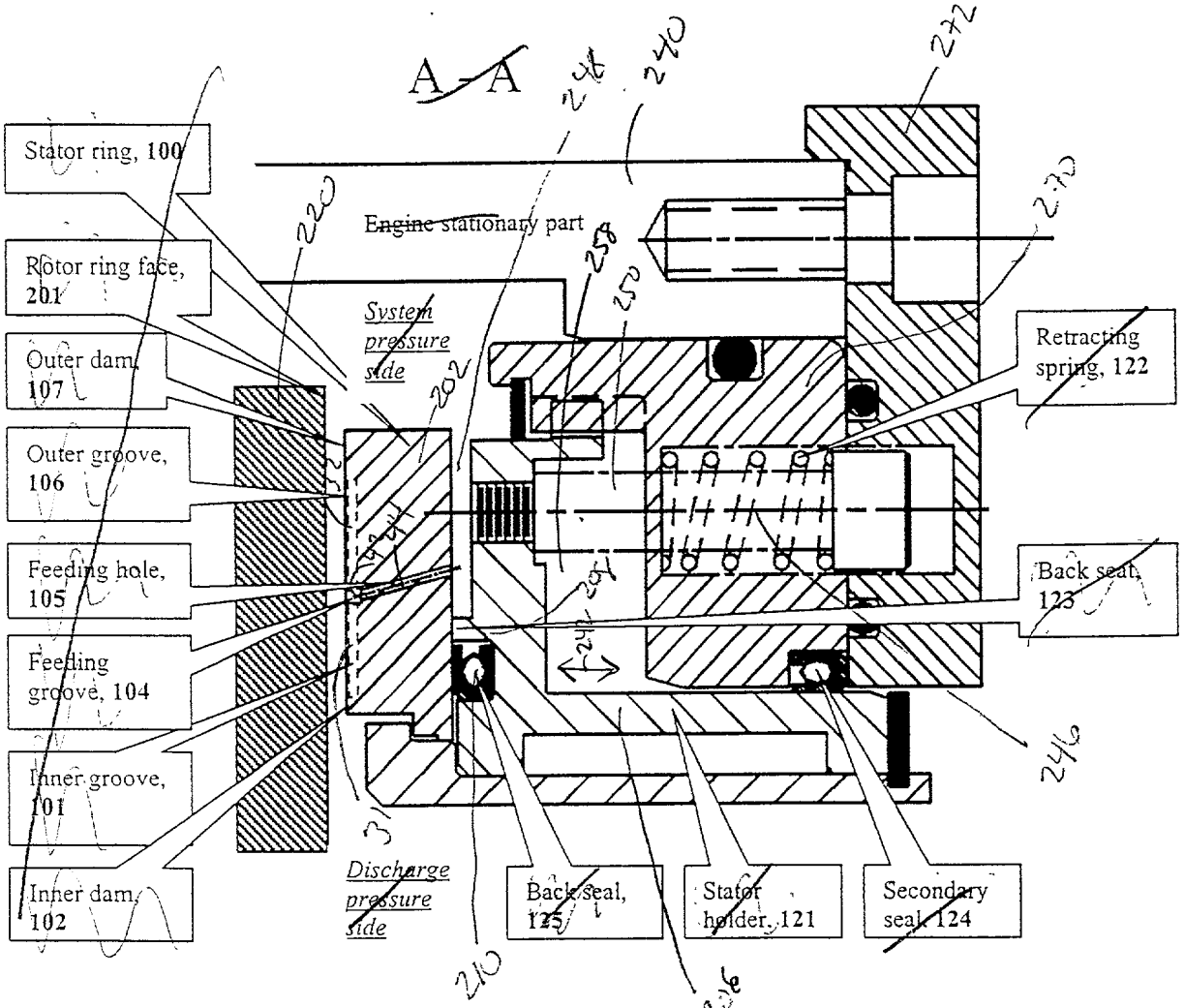

Figure 4. Seal cross section

FIG 21

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